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TITLE:	MANUAL METAL ARC WELDING – A BRIEF NOTE ON THE PROCESS & PARAMETERS

CONTENTS:

1.0 INTRODUCTION:

Among the arc welding processes, Manual metal arc welding (MMAW) or Shielded metal arc welding (SMAW) is most common, versatile and inexpensive. The electrode melts in the weld arc and gets deposited on the adjoining surface. MMAW process accounts almost 80% of the total welding in India. It is suitable for any range of plate thickness and can be used for all commercial metal & alloys.

The process comprises of a Power source, MMAW electrode and the connecting cables (as shown in figure-1). SMAW electrodes are available in a wide range of diameters. Generally for all commercial fabrication, the diameter of the electrodes lies between 1.6 to 6.3mm, considering the thickness of the plate. The welding operation is schematically shown in figure-2.

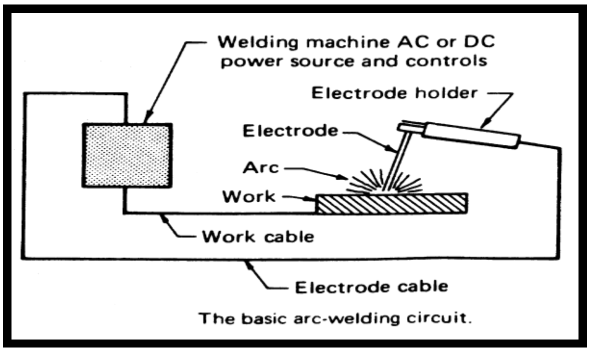

Figure-1: Schematic representation of MMAW process

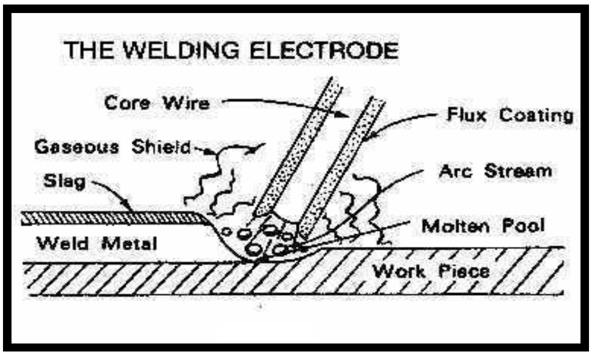

Figure-2: Schematic sketch of burning of MMAW electrodes

SWAW electrode comprises of two components - the core wire and the outer flux coating. While the arc protection is the primary function of the flux coating, it has lot of other functions to do.

1. Produces slag after melting which further protects the molten weld metal from oxidation.
2. Provides alloying to achieve alloy steel weld metal.
3. Helps to deoxidize and refine the weld metal.
4. Stabilizes the arc during welding and helps to work in different welding positions.
5. Provides a mean to add iron powders for high deposition efficiency electrode.

2.0 THE VARIOUS STAGES OF MANUFACTURING OF MMAW ELECTRODES:

The manufacturing processes of SMAW/ MMAW electrodes can be divided into four distinguished stages.

Stage-1: Dry mixing the ingredients - Flux on the electrode coating is a mixture of various inorganic minerals (like, calcite, china clay, fluorspar, rutile sand, quartz etc.), de-oxidizers and ferro-alloys. These ingredients are thoroughly mixed to form a homogeneous mix.

Stage-2: Wet mixing the flux - An appropriate addition of binder (sodium/ potassium silicate) is mixed with the dry flux to form a wet lump. The wet mass is compacted to form briquettes in a hydraulic press are known as 'cake'. Cakes are fed in the extruder.

Stage-3: Extrusion - It is the heart of the electrode manufacturing process. Our extruders are of co-axial type, wherein the core wire comes out with flux covering with application of pressure. The outer diameter is pre-selected depending on the electrode design. These electrodes are called 'green electrodes'.

Stage-4: Drying/ baking - The green electrodes are air-dried for 8-24 hrs and then heated in an oven to drive-off the moisture in the coating originated from the silicate binders.

The finished products are then checked & tested as per the quality-check procedures. Electrodes are first packed in paper cartons and then five such cartons in a corrugated box for dispatch.

3.0 COMMON MMAW ELECTRODES – E6013 & E7018 TYPE:

3.1 E6013 electrodes

E6013 class as per AWS SFA 5.1 is classified as "high titania potassium type covering" suitable for ac, dcep or dcen current working in flat, vertical, overhead & horizontal welding applications. The flux covering makes easier slag removal and smoother arc transfer in E6013 electrodes. Few of this class of electrodes are suitable for vertical down welding position also.

The salient characteristic of this class of electrodes is satisfactory operation with lower open circuit voltage (OCV). This means the electrodes operate even on a 50 OCV transformer. They are designed specifically for light sheet metal work and lower strength applications.

However, E6013 class electrodes are limited in areas where high strength, thick plate joining are required and also for jobs which may undergo dynamic loading in service.

3.2 E7018 electrodes

In E7018 class, the type of covering is classified as “low hydrogen potassium with iron powder” recommended for ac or dcep current condition. These electrodes are also known as “Low hydrogen” electrodes wherein the slag is chemically basic in nature.

They are used for joints involving high strength, high carbon and low alloy steels. The fillet welds made in the horizontal & flat welding position have a slightly convex weld face with a smooth & finely rippled surface.

Basic type MMAW electrodes deposit lower hydrogen level in the weld metal compared to rutile type electrodes. Depending on the design, the diffusible hydrogen generally lies between 3-10ml per 100 gms of weld metal. But in case of rutile type electrodes it is much higher (above 15ml/ 100 of weld metal).

4.0 MOISTURE IN FLUX COATING

Moisture in a basic type flux coated electrodes is very significant. In the welding arc, it dissociates into atomic hydrogen and oxygen. As oxygen reacts to form oxides, hydrogen goes into deposited weld metal. The presence of hydrogen is reported in the host lattice and in the atomic & micro-structural defects such as vacancies, dislocations, grain boundaries, micro-voids and second phase particles. The dissolved hydrogen then assists in the fracture of the metal, possibly by making cleavage easier or possibly by assisting in the development of intense local plastic deformation. These effects lead to embrittlement of the metal; cracking may be either inter-granular or trans-granular. Crack growth rates are typically relatively rapid, up to 1 mm/s in the most extreme cases. So, the presence of hydrogen is controlled in the high strength weld metals especially when the strength crosses beyond the 80 ksi values.

Control on moisture in the electrode coating leads to various grades of low hydrogen electrodes. H15, H10, H5 wherein 15, 10 & 5ml of diffusible hydrogen is specified in 100 grams of weld metal. However, as the propensity of such crack formation increases with the strength of the weld, it is always desired to have an extra low hydrogen electrode (below 3ml) for joining high strength steels.

A major proportion of basic-coated electrodes ingredients are hygroscopic in nature. This makes the basic type electrodes highly prone to moisture pick up, aggravating the tendency to deposit high-hydrogen weld metal.

A fresh electrode immediately after baking (400-500°C) shows between 0.20-0.25% moisture in the flux coating. However, when left open in an open atmosphere, it picks up moisture. The moisture content of the coating flux may go beyond 1.0% depending on the duration and condition of exposure.

These types of electrodes therefore, need re-drying prior to use to drive-off the moisture from the electrode coating. It is generally done at 300-350°C for 2 hours or followed as per the recommendations of the electrode manufacturer.

Limited data are available in the literatures to establish a relation between moisture content & diffusible hydrogen content of the weld metal. Also, these values are dependant on specific flux design. However, studying the various results and also from the analyses of available data in the literatures, it can be assumed that, to restrict hydrogen content below 5.0ml per 100gms of weld metal, the moisture content of the coating shall not exceed 0.48% at the time of welding.

5.0 HYDROGEN-INDUCED CRACKING (HIC) IN WELDMENTS

Hydrogen-induced cracking is also known as cold cracking or delayed cracking or under-bead cracking. It also occurs in steel during manufacture, during fabrication and in service. It is thus not confined to welding, but when it occurs as a result of welding the cracks are either in the heat affected zone (HAZ) of the parent metal or in the weld metal itself.

5.1 Cracking in the HAZ

The conditions favourable for cracking can be summarized as –

1. **Presence of Hydrogen**- derived from moisture in the fluxes used in welding and from other sources.
2. **Tensile stresses act on the weld**- these stresses form due to thermal fluctuations during welding and rigidity of the joint.
3. **A susceptible HAZ micro-structure**- coarse grained region, martensitic microstructure formed during welding.

5.2 Cracking in the Weld metal

As the alloying content of both weld metal & parent metal increases, the susceptibility of cracking in the weld increases. If they originate in the root they are longitudinal to the weld. If they are buried or are at the surface, they may be trans-granular to the weld.

During welding, hydrogen is absorbed by the weld pool from the arc atmosphere. Though, much of this hydrogen escapes during cooling from the solidified bead by diffusion but some also diffuses out into the HAZ and the parent metal. This distribution depends on several factors, such as the original amount absorbed, the size of the weld, the decreasing solubility and the time-temperature conditions of cooling.

In general, more hydrogen present increases the risk of cracking. The principal sources of hydrogen from the material to be welded are:

1. Oil, grease, dirt, rust, paint, etc on the surface and adjacent to the weld preparation.
2. Degreasing fluid used to clean surfaces before welding.

The principal sources of hydrogen in the welding consumables are:

1. Moisture in the coating of MMAW electrodes, fluxes in the SAW process and the fluxes used for FCAW process.
2. Any other hydrogenous compounds in the coating flux.
3. Oil, dirt, grease, etc either on the surface or trapped in the surface layers of welding wires and electrode core wires.

4. Presence of rust on the surface of the base metal or on the welding wires.

5.3 Measures to avoid Hydrogen induced cracking (HIC)

The steps to reduce the propensity for HIC can be summarized as:

1. Re-dry the SMAW electrode and SAW flux at 300-350°C for 2 hours or as per the recommendations of the consumable manufacturer prior to use.
2. Preheat & inter-pass temperature depending on the chemistry & joint thickness.
3. Proper joint fit up to reduce the restraints.
4. Cleanliness of the adjoining surfaces
5. Multi-run welding procedure.
6. Post weld heat treatment.

6.0 VACUUM PACKING OF MMAW ELECTRODES:

It is a well-established fact that for any critical applications, basic type electrodes are more preferred over rutile type electrodes. The lower oxygen & diffusible hydrogen content of the deposited weld metal along with a better alloy recovery made basic coated electrode a worldwide choice for all special and critical applications. However, basic type flux coatings of SMAW electrodes generally are very prone to moisture pick up when exposed to open atmosphere. The reason is attributed to the nature & characteristics of the ingredients like; Calcite, Magnesite, Flourspar, etc. present in the basic type flux coating. They pick up moisture, which after dissociation in the welding arc cause hydrogen transfer in the deposited weld metal resulting in cold (hydrogen assisted) cracks in due course of time.

In this context, re-drying of the electrodes prior to use plays a significant role to achieve the desired mechanical properties. This is a mandatory practice for all basic coated electrodes and generally re-dried at 300-350°C for one hour as per the manufacturer's recommendations prior to use. In case of improper re-drying, the diffusible hydrogen content of the weld metal may be more than the specified level and for a fabricated structure subjected to dynamic loading may suffer from a catastrophic failure in service. As a good shop floor practice, electrodes packed under vacuum may be a preferred choice for any fabricator.

6.1 Advantages of vacuum packing of electrodes

During vacuum packing, the electrodes after baking & cooling are first put in card-board carton and then in a HDPE carton and vacuum sealed. The advantages achieved with this type of special packaging are as follows.

1. Elimination of re-drying process of at the shop floor.
2. Quick on-job weld starting time – time loss for electrode re-drying is eliminated.
3. More welder-friendly, can easily be carried to any odd site location instead of carrying the electrode holder oven.
4. Reduced variations of weld metal hydrogen content due to improper re-drying.
5. Facilitates better handling with a handy pack of 1.0/ 2.0kg pack electrode.
6. Improved shelf life for the electrodes.

6.2 Low hydrogen electrodes storage conditions (clause 4.5.2 of AWS D1.1)

All electrodes having low hydrogen covering conforming to AWS 5.1 shall be purchased in hermetically sealed containers or shall be dried for at least two hours between 260°C to 430°C before they are used. Electrodes conforming to AWS 5.5 shall be purchased in hermetically sealed containers or shall be dried for at least one hour between 370°C to 430°C before they are used. If the hermetically sealed container shows evidence of damage, electrodes shall be dried prior to use.

Electrodes shall be stored in ovens held at a temperature of at least 120°C, immediately after opening of hermetically sealed container or removal of the electrodes from drying ovens.

Electrodes that conform to this provision shall subsequently be re-dried no more than one time. Electrodes that have been wet shall not be used.

When welding for ASTM A514 or ASTM A517 grade steels, electrodes of any classification lower than E100XX-X, except for E7018M and E70XXH4R, shall be dried at least one hour at temperatures between 370°C to 430°C before being used, whether furnished in hermetically sealed containers or otherwise.

6.2.1 Approved atmospheric exposure time periods

The allowable time of exposure for vacuum packed electrodes or after re-drying the electrodes is mentioned in the clause 4.5.2.1 of Structural welding code for Steel (AWS D 1.1). After hermetically sealed containers are opened or after electrodes are removed from drying or storage ovens, the electrode exposure to the atmosphere shall not exceed the values mentioned in the Table-1.

Alternatively, atmosphere exposure time period may be established by conducting some tests. These electrodes shall not be exposed at relative humidity-temperature combinations that exceed either the relative humidity or moisture content in the air that prevailed during the testing program (as shown in Fig-3).

Table-1: Permissible atmospheric exposure of low hydrogen electrodes

Electrode/ A5.1	Exposure time, hrs
E70XX	4 max
E70XXR	9 max
E70XXHZR	9 max
E7018M	9 max

Electrode/ A5.5	Exposure time, hrs
E70XX-X	4 max
E80XX-X	2 max
E90XX-X	1 max
E100XX-X	½ max
E110XX-X	½ max

Note: Electrodes exposed to atmosphere for longer periods than shown or longer than those established by testing shall be re-dried before use.

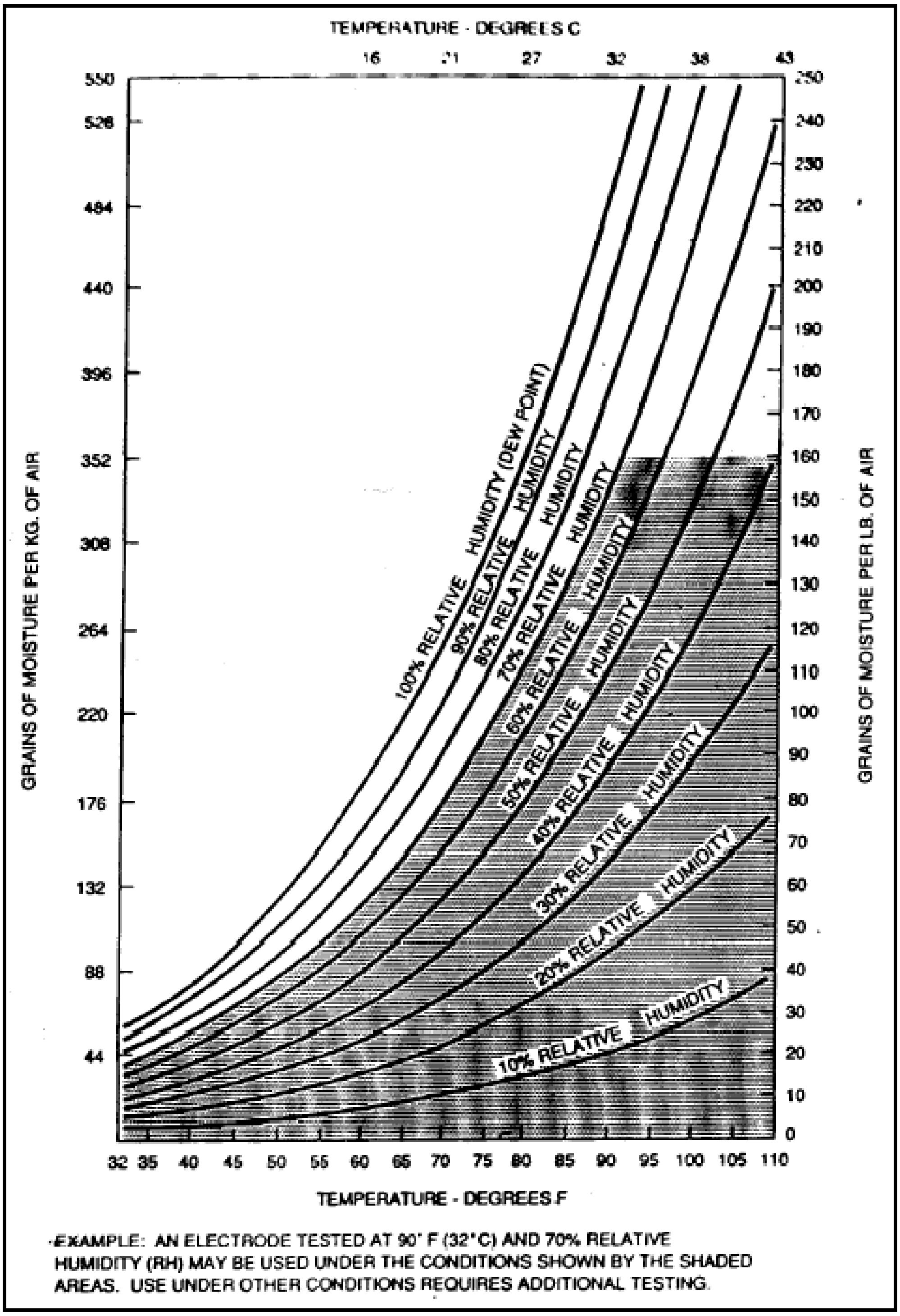

Figure-3: Application of temperature-moisture content chart in determining atmosphere exposure time for low hydrogen electrodes (Ref: fig: VIII-2, section 4.5.2 of AWS D1.1: Structural welding Code of Steel)

7.0 SOME EXPERIMENTAL DATA FOR VACUUM PACKED ELECTRODES

Propensity of electrodes to moisture pick up after opening the vacuum pack were studied after exposing them to 80% RH and 26.7°C temperature up to 9 hours. Results are summarized in Table-2.

Table-2: Coating moisture of E7018 type electrodes with modified binder

	Exposure Time, hrs (80% RH and 26.7°C)					
	0	2	4	6	8	9
Coating moisture	0.17	0.31	0.31	0.29	0.31	0.32

AWS moisture & diffusible H_2 after 9 hours of exposure were 0.32% and 2.81ml respectively.

8.0 STEPS OF MANUFACTURING THE VACUUM PACKED H4R ELECTRODES

1. Selection of dry flux mix.
2. Selection of binder (A different binder for H4R electrodes).
3. Selection of extrusion parameters and air-drying time (24 hrs minimum) as per the design.
4. Baking of the electrodes shall be done at 460°C with holding for 90 minutes. Rate of heating shall be below 100°C & cooling shall be done in oven till 100°C without opening the door.
5. The moisture content of the flux coating shall be checked in a “Moisture balance” immediately after the electrodes are taken out from the oven after baking. The value generally lies between 0.20-0.23%.
6. For H4R class, the electrode shall be tested for coating moisture as per the AWS requirement (Exposing at 80% RH and 26.7°C for 9 hours).
7. In an ideal condition, the electrode shall be vacuum packed immediately. However, if there is any constraint, the electrodes may either be kept in the oven at ~50°C with proper air circulation by fans or shall be stored in a de-humidifier room wherein the relative humidity is maintained below 30% and

temperature is 5-10°C more than the surrounding atmospheric temperature_till they are taken up for packing.

8. The flux moisture content of the electrode shall again be checked in a "Moisture balance" when they are taken up for vacuum packing. The value of moisture content of the flux (during entire packaging operation) measured prior to start of the packaging and the time of last electrode being packed from the stand shall not be more than 0.25%.

9.0 EFFECT OF ALLOYING ELEMENTS IN THE C-Mn STEEL WELD METAL

9.1 Effect of Carbon:

- Linearly increases the yield and tensile strength.
- The hardness increases.
- Promotes precipitation of the secondary phases.
- The optimum C at 1.4% Mn for improved mechanical properties is 0.06 to 0.09.

9.2 Effect of Manganese:

- Increased from 0.6 to 1.8%, acicular ferrite percentage increases.
- Increasing Mn, refines the acicular ferrite of the as-deposited weld metal, that improves the notch toughness of the weld metal
- YS and UTS of the weld deposits increase almost at a rate 10 MPa / 0.1%.

9.3 Effect of Silicon:

- Increasing Si, weld metal oxygen content decreases.
- Hardness, YS and UTS increases with Si.
- Notch toughness is deteriorated with same Mn content.
- A maximum 0.5% Si content is tolerated at an optimum Mn in as-weld applications.

9.4 Effect of Sulfur & Phosphorus:

- S & P both are in general detrimental to the weld metal, increases the volume % of inclusions.
- S lowers hardness, decreases tensile strength and drastically reduces notch toughness.
- P increases hardness and tensile properties but had little effect on notch toughness (as reported for the range 0.007 to 0.040%).

-X -